Ultrasound Guided Placement of External Fixator Pins: an Assessment of Accuracy

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Introduction:

Forward-deployed Military Treatment Facilities (MTFs) are configured to perform initial assessment and stabilization of extremity injuries under austere conditions. Under varying operational conditions, these highly mobile medical platforms may be required to relocate in support of parent combat units. As such, limitations on the size and weight of unit deployment blocks constrain the equipment allocated in support of initial care and stabilization of military casualties in forward areas.

The acute resuscitation of patients injured under combat conditions follows ATLS algorithms proposed by the American College of Surgeons Committee on Trauma. Cervical spine protection is instituted, followed by rapid assessment of the airway, ventilation, and circulatory status. The primary survey includes a rapid evaluation of central and peripheral neurological status. In the more specific secondary survey, extremity injuries are noted. Following a careful examination to document neurological status of the extremities, provisional treatment should be instituted. Screening radiographs are obtained to provide information regarding potential injuries of the cervical spine, thorax, abdomen, and extremities. In forward-deployed MTFs, radiographic capability is limited to small 25 mA plain-film radiography units. The low power of these units restricts tissue penetration; therefore the diagnostic quality of the images obtained from these units is limited.

Following airway stabilization and volume resuscitation, management of extremity injuries is instituted. Wounds are debrided, irrigated, and skeletal stabilization may be performed. As military extremity injuries typically involve severe tissue contamination, comminution of fracture segments, and delays in extrication to medical treatment, careful osteosynthesis, intramedullary rod fixation, and wound closure are all strongly condemned. Definitive care may be remote from the injury site or subject to transportation delays. Rear-echelon units maintain technical resources and specialty care to perform definitive stabilization, internal fixation, and reconstructive procedures under improved conditions and on fully resuscitated patients.

In the presence of comminuted, high-energy wounds (as seen in explosive fragmentation injuries), stabilization of the fracture fragments and overlying soft tissues offers profound benefits: limitation of ongoing blood loss and reduction in analgesic requirements. External fixation provides excellent provisional fixation while facilitating access for wound care (12,13).

Traditional pin insertion utilizes the use of real-time fluoroscopy to guide site selection, pin orientation, and prevent over-penetration of the far cortex. Fluoroscopy is not currently available in forward MTFs. External fixation will be performed in the absence of real-time radiographic visualization. As previously mentioned, plain film capability is similarly constrained. Forward surgical teams (FST), Medical Company facilities, and Fleet Hospital units do possess small portable ultrasound units to assess the presence of intrapelvic and intraabdominal fluid. These devices have been used successfully to guide decision-making regarding the indications for exploratory celiotomy.

Use of ultrasonographic diagnostic imaging is well established in Obstetrical and General Surgical practice. Similarly, the use of ultrasonographic imaging technology is not new to the practice of Orthopaedic surgery. Ultrasound gained popularity as a diagnostic tool 10-15 years ago, offering real-time visualization of soft tissue injuries around the shoulder and for tendon ruptures (need reference). Ultrasonography offered a non-invasive option to contrast arthrography in detecting rotator cuff injuries. Diagnostic ultrasonography suffered from low specificity and operator familiarity. It has now been largely supplanted by the more sensitive and specific MRI technology. Despite the increasing roles for diagnostic ultrasonography

in Obstetrical and General Surgical practices, orthopaedic practices utilize ultrasound technology almost exclusively as s a theraputic modality.

In a review of International literature, recent reports have documented the rare use of ultrasonographic imaging in the management of fractures. Ultrasound-assisted fracture reduction has been described to facilitate the cannulation of intramedullary canals for rod placement, and in guiding the removal foreign bodies from soft tissues (3-9). One report demonstrated that high-resolution ultrasound imaging was capable of detecting a cortical discontinuity as small as 1mm in cadaveric long bones (8). To our knowledge, the use of ultrasound imaging to guide the placement of Shantz pins for external fixation constructs has not been described in the English literature (1). The purpose of this study was to explore the accuracy of the ultrasound devices in measuring penetration of Shantz pins from the far cortex in fresh cadaveric limbs.

Materials and Methods:

Four self-drilling, self-tapping threaded 4.0mm Schanz Pins (Howmedica inc. Rutherford, New Jersey) were placed into fresh cadaveric specimens. Two cadavers were used to provide four limbs for testing. The limbs were not prepared in any manner. A small incision was made in the skin and a limited blunt dissection made through the soft tissues to the diaphyseal cortex. The self-drilling, self-tapping pins were easily placed by hand. An orthopaedic resident (MK) and an orthopaedic staff traumatologist (RBS) performed pin placement. One pin was placed from lateral to medial in the distal one-third of the femoral diaphysis. The remaining three pins were placed in the proximal tibia, the midshaft of the tibia, and the distal tibia, respectively. These pins were placed from anteromedial to posterolateral utilizing the "safe zones" as described by Behrens et al (11). All pins were inserted to engage both near and far cortex. In order to present a broad range of potential measurements, pins were placed to variable random depths.

Ultrasound monitoring was performed using one of three available ultrasound devices. (Sonosite 180 Plus with L-38 transducer [10-5MHz], GE Logic 700 [7-10MHz] and Accuson Sequioia 512 [8-15 MHz]). Depth-of-penetration measurements were then performed on Specimen A using the Sonosite ultrasound device (2) (figure 6). On the second (Specimen B) and third cadaver (Specimen C and D), the larger ultrasound units were used. The linear transducers were used in all devices. Depth measurements were taken directly from the screen. Pin measurements were taken from the most distal portion of the pin tip to the closest aspect of the cortex from which the pin emerged. The location of the pin and point of penetration were determined by the distances between the clearly visible dense echogenic outer cortices of bone and the linear reflection off the pin and threads (figures 1,2). The same orthopaedic resident and orthopaedic staff as well as two staff radiologists (AG, VH) performed the sonographic measurements independently. The specimens were then dissected to measure the depth-of-penetration of each pin from the surface of the far cortex. Measurements were made using a metallic ruler. All direct measurements were performed by one observer to eliminate technique bias in judging the distance of the pin tip from the bone cortex.

Results:

Comparisons of the ultrasound and post-dissection measurements are shown in Table 1. Sixteen pins were placed into the lower extremities with a total of 56 measurements taken. A broad range of actual pin penetration measurements was present (1.5-23.0 mm). Measurements taken from cadavers 1-3 are shown in Figure 4. The greatest difference between ultrasound and cadaveric measurements was 8.0mm for one measurement by one observer.

Statistical analysis:

In order to evaluate the tendency of the technique to misrepresent the true measurement, data from cadaver 3 (Figure 5) was analyzed using simple linear regression and found to be highly accurate (mean difference 2.612 mm, p-value 0.0007). Inter-observer data were analyzed statistically with an analysis of variance (ANOVA). No significant difference was found between the examiners. (F value 0.007, Figure 3)

Discussion:

We describe the accuracy of a new application for the portable ultrasound unit in guiding the placement of Shantz pins during extremity fracture external fixation.

Practitioners generally unfamiliar with the technique of external fixation often express concern for inadvertent injury to deep structures during pin penetration through the far cortex. We endeavored to evaluate the capability of ultrasound devices (including a small portable model available in forward-deployed MTFs) to accurately depict and measure the penetration of the far cortex by Shantz pins during placement.

In evaluating the accuracy of the devices, we compared the true measurements to observed measurements. We attempted to set 95% confidence limits. If we defined accuracy as being within 2mm of the actual depth, our results suggest that ultrasound is accurate 73% of the time (Table 2). The overall percentage of measurements falling within 3 mm of the true measurement was 77%. At 4 and 5 mm, the percentages were 88 and 91%, -respectively (Tables 3 – 5). To set perspective, the distance from the tip of a Schanz pin to the first two threads is 5mm. Accordingly, we believe this variability in measurement reflects no appreciable clinical significance We also compared the tendency for measurements to vary among observers in an attempt to detect trends in accuracy reflecting different levels of training or level of comfort with the ultrasound device. We saw no such trends, suggesting that the technique is simple and reliable.

We utilized the linear transducers available for each unit. The devices' flat surface offered excellent contact with the skin overlying the long bones, a distinct advantage over the other transducers available for each device. We found no significant variation in accuracy between the levels of training as Orthopaedists, nor between Orthopaedist and Radiologists. We noted a slight reduction in the variability between the first and final measurements. While not statistically significant, this trend may suggest that we became more proficient with the technique. Interestingly, this variability was seen for all observers, for Radiologist and Orthopaedist alike, suggesting a very short learning curve under these conditions. The data for Cadaver 3 reveal the pattern of consistent measurements supporting this conclusion. (Figure 4).

While the Sonasite device was not specifically tested under arduous circumstances in this study, one of us (RBS) has used the device in adverse field environments simulating Field Hospital settings on several occasions. In one circumstance, the damp weather conditions destroyed co-located telemedicine equipment. The Sonasite device remained fully operational. We believe the device is simple to operate, durable, and offers accurate measurements for this application.

Throughout our study, access to the Ultrasound device depended on available clinical units, so not all measurements were made using all units. The Sonasite device was available only during the initial measurements on Cadaver 1 and 2. During measurements for Cadaver 3, alternate devices were utilized. It is possible that

improved accuracy noted on Figure 3 represents variability between machine displays. Additionally, all examiners did not measure all pins. Examiner #2 did not participate in taking measurements on Cadaver 3. Correspondingly, we did not include that examiner's data into the overall analysis of variance or the linear regression analysis.

Conclusion:

Our results indicate that ultrasound, despite its inherent inability to penetrate bone, can be a valuable alternate modality. The technique offers both the capability to accurately measure pin penetration from the far cortex, but also provides real-time monitoring thereby minimizing the risk of unintentional injury to surrounding structures. In our experience, we were readily able to observe a display of cortical breakthrough while advancing the Shantz pin.

Although ultrasound monitoring is not the ideal form of visualization for fracture reduction, it is a modality that is readily available, accurate, inexpensive, and portable modality that can provide the forward deployed surgeon the imaging needed for rapid application of an external fixator to establish provisional fracture stabilization.

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Table 1

Pin Measurements (mm)

Specimen	Examiner 1	Examiner 2	Examiner 3	Examiner 4	Actual
A					
Dist. Tibia	5.5	4.2	2.0	4.2	5.5
Mid Tibia	10.5	8.5	10.9	10.3	12.0
Prox. Tibia	5.0	2.7	3.7	1.2	5.5
Femur	10.4	2.8	0.0	4.2	8.0
B					
Dist.Tibia	1.9	2.0	2.1	1.9	1.5
Mid Tibia	3.4	3.6	3.0	3.6	2.0
Prox. Tibia	3.7	5.5	8.0	5.2	4.5
Femur	3.6	4.5	3.3	1.8	5.0
C					
Dist. Tibia	4.9	**	0.0	4.0	6.0
Mid Tibia	12.8	**	11.7	10.4	16.0
Prox. Tibia	6.3	**	5.7	5.6	6.0
Femur	11.0	**	10.3	13.0	12.0
D					
Dist. Tibia	6.0	**	12.8	4.6	4.0
Mid Tibia	22.9	**	20.8	24.0	23.0
Prox. Tibia	4.2	**	4.3	5.0	4.0
Femur	11.1	**	10.8	10.2	11.0

** Examiner 2 not present for specimens C and D

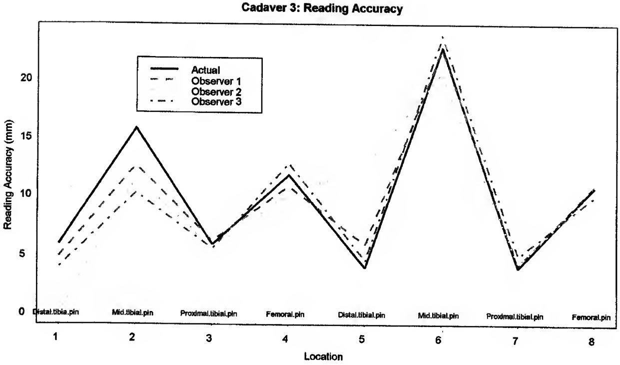

Figure 3.

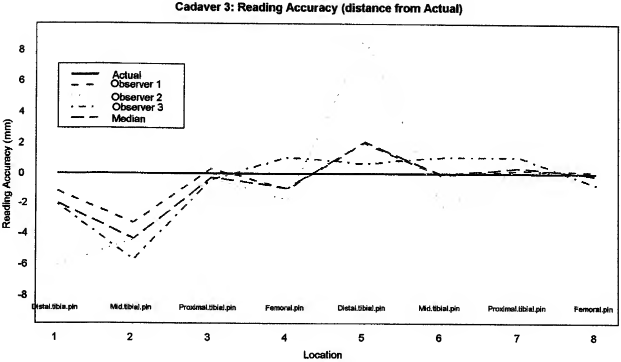

Figure 4.

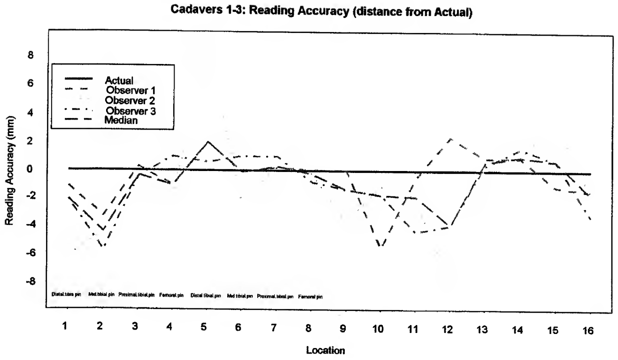

Figure 5.

Location 1-8 taken from Specimen C and D (Cadaver 3)
Location 9-12 taken from Specimen B (Cadaver 2)
Location 13-16 taken from Specimen A (Cadaver 1)

Table 2

The following table presents the proportion and percentage of observer measurement falling within 2mm of the actual measurement for each location, each cadaver. The overall percentage of ultrasound measurements falling within this range was 73%.

Cadaver	Location	Actual(mm)	Range (+/- 2mm)	Proportion in range
1.	Dist. Tibia	5.5	3.5 – 7.5	3/4
	Mid Tibia	12.0	10.0 – 14.0	3/4
	Prox. Tibia	5.5	3.5 – 7.5	2/4
	Femur	8.0	6.0 – 10.0	1/4
2	Dist. Tibia	1.5	0 – 3.5	4/4
	Mid Tibia	2.0	0 – 4.0	4/4
	Prox. Tibia	4.5	2.5 – 6.5	3/4
	Femur	5.0	3.0 – 7.0	3/4
3(Right)	Dist. Tibia	6.0	4.0 – 8.0	2/3
	Mid Tibia	16.0	14.0 – 18.0	0/3
	Prox. Tibia	6.0	4.0 – 8.0	3/3
	Femur	12.0	10.0 – 14.0	3/3
3(Left)	Dist. Tibia	4.0	2.0 – 6.0	2/3
	Mid Tibia	23.0	21.0 – 25.0	2/3
	Prox. Tibia	4.0	2.0 – 6.0	3/3
	Femur	11.0	9.0 – 13.0	3/3
				41/56 (73%)

Table 3

The following table presents the proportion and percentage of observer measurement falling within 3 mm of the actual measurement for each location, each cadaver. The overall percentage of ultrasound measurements falling within this range was 77%.

Cadaver	Location	Actual(mm)	Range (+/- 3mm)	Proportion in range
1.	Dist. Tibia	5.5	2.5 – 8.5	3/4
	Mid Tibia	12.0	9.0 – 15.0	3/4
	Prox. Tibia	5.5	2.5 – 8.5	3/4
	Femur	8.0	5.0 – 11.0	1/4
2	Dist. Tibia	1.5	0 – 4.5	4/4
	Mid Tibia	2.0	0 – 5.5	4/4
	Prox. Tibia	4.5	1.5 – 7.5	3/4
	Femur	5.0	2.0 – 8.0	3/4
3(Right)	Dist. Tibia	6.0	3.0 – 9.0	2/3
	Mid Tibia	16.0	13.0 – 19.0	0/3
	Prox. Tibia	6.0	3.0 – 9.0	3/3
	Femur	12.0	9.0 – 15.0	3/3
3(Left)	Dist. Tibia	4.0	1.0 – 7.0	2/3
	Mid Tibia	23.0	20.0 – 26.0	3/3
	Prox. Tibia	4.0	1.0 – 7.0	3/3
	Femur	11.0	8.0 – 14.0	3/3
				43/56 (77%)

Table 4

The following table presents the proportion and percentage of observer measurement falling within 4mm of the actual measurement for each location, each cadaver. The overall percentage of ultrasound measurements falling within this range was 88%.

Cadaver	Location	Actual (mm)	Range (+/- 4mm)	Proportion in range
1.	Dist. Tibia	5.5	1.5 – 9.5	4/4
	Mid Tibia	12.0	8.0 – 16.0	4/4
	Prox. Tibia	5.5	1.5 – 9.5	3/4
	Femur	8.0	4.0 – 12.0	2/4
2	Dist. Tibia	1.5	0.0 – 5.5	4/4
	Mid Tibia	2.0	0.0 – 6.0	4/4
	Prox. Tibia	4.5	0.5 – 8.5	4/4
	Femur	5.0	1.0 – 9.0	4/4
3(Right)	Dist. Tibia	6.0	2.0 – 10.0	2/3
	Mid Tibia	16.0	12.0 – 20.0	1/3
	Prox. Tibia	6.0	2.0 – 10.0	3/3
	Femur	12.0	8.0 – 16.0	3/3
3(Left)	Dist. Tibia	4.0	0.0 – 8.0	2/3
	Mid Tibia	23.0	19.0 – 27.0	3/3
	Prox. Tibia	4.0	0.0 – 8.0	3/3
	Femur	11.0	7.0 – 15.0	3/3
				49/56 (88%)

Table 5

The following table presents the proportion and percentage of observer measurement falling within 5mm of the actual measurement for each location, each cadaver. The overall percentage of ultrasound measurements falling within this range was 91%.

Cadaver	Location	Actual (mm)	Range (+/- 5mm)	Proportion in range
1.	Dist. Tibia	5.5	0.5 -10.5	4/4
	Mid Tibia	12.0	7.0 – 17.0	4/4
	Prox. Tibia	5.5	0.5 – 9.5	4/4
	Femur	8.0	3.0 – 13.0	2/4
2	Dist. Tibia	1.5	0.0 – 6.5	4/4
	Mid Tibia	2.0	0.0 – 7.0	4/4
	Prox. Tibia	4.5	0.0 – 9.5	4/4
	Femur	5.0	0.0 – 10.0	4/4
3(Right)	Dist. Tibia	6.0	1.0 – 11.0	2/3
	Mid Tibia	16.0	11.0 – 21.0	2/3
	Prox. Tibia	6.0	1.0 – 11.0	3/3
	Femur	12.0	7.0 – 17.0	3/3
3(Left)	Dist. Tibia	4.0	0.0 – 9.0	2/3
	Mid Tibia	23.0	18.0 – 28.0	3/3
	Prox. Tibia	4.0	0.0 – 9.0	3/3
	Femur	11.0	6.0 – 16.0	3/3
				51/56 (91%)

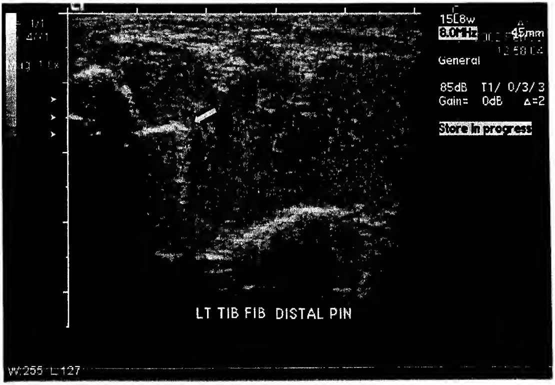

Figure 1

Transverse image at distal tibia revealing the bright signal representing the pin exiting from the far tibial cortex. The pin tip is clearly visible (arrow)

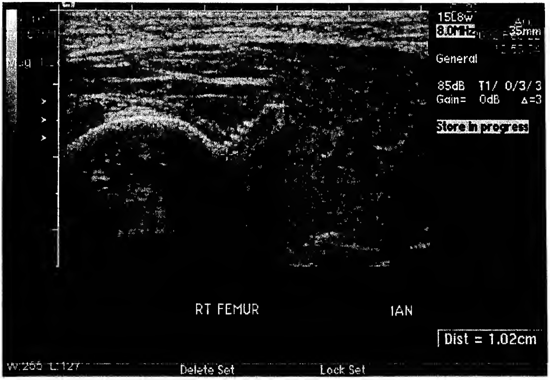

Figure 2

Transverse image of Shantz pin penetration through medial femoral cortex. The pin tip and threads are clearly visible. Measurement of pin penetration by the device is 1.02cm.

Figure 6
Image of pin penetration using the Sonosite device prior to calibration of the measurement tool. The pin tip can be noted emerging from the right side of the central figure as a bright signal. The measuring tool is placed on the pin tip.